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Bayesian calibration of a soil organic carbon model with radiocarbon measurements of heterotrophic respiration and soil organic carbon as joint constraints

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Soils of temperate forests store significant amounts of organic matter and are considered to be net sinks of atmospheric CO_2. Soil organic carbon (SOC) dynamics have been studied using the $\Delta^{14}C$ signature of bulk SOC or different SOC fractions as observational constraints in SOC models. Further, the $\Delta^{14}C$ signature of CO_2 evolved during the incubation of soil and roots has been widely used together with $\Delta^{14}C$ of total soil respiration to partition soil respiration into heterotrophic respiration (HR) and rhizosphere respiration.

However, this data has not been used as joint observational constraints to determine SOC turnover times. Thus, we want to present: (1) how different combinations of observational constraints help to narrow estimates of turnover times and other parameters of a simple two-pool model, ICBM; (2) if a multiple constraints approach allows determining whether a forest soil has been storing or losing SOC. To this end ICBM was adapted to model SOC and $SO^{14}C$ in parallel with litterfall and the $\Delta^{14}C$ signature of litterfall as driving variables. The $\Delta^{14}C$ signature of the atmosphere with its prominent bomb peak was used as a proxy for the $\Delta^{14}C$ signature of litterfall. Data from three spruce dominated temperate forests in Germany and the USA (Coulissenhieb II, Solling D0 and Howland Tower site) were used to estimate the parameters of ICBM via Bayesian calibration.

Key findings are: (1) the joint use of all 4 observational constraints helped to considerably narrow turnover times of the young pool (primarily by $\Delta^{14}C$ of HR) and the old pool (primarily by $\Delta^{14}C$ of SOC). Furthermore, the joint use all observational constraints allowed constraining the humification factor in ICBM, which describes the fraction of the annual outflux from the young pool that enters the old pool. The Bayesian parameter estimation yielded the following turnover times (median $\pm$ interquartile range) for SOC in the young pool: Coulissenhieb II 2.9 $\pm$ 2.1 years, Solling D0 8.4 $\pm$ 1.6 years and Howland Tower 3.3 $\pm$ 2.4 years. Turnover times for the old pool were 385 $\pm$ 92 years (Coulissenhieb II), 134 $\pm$ 38 years (Solling D0) and 205 $\pm$ 76 years (Howland Tower), respectively.

(2) At all three sites the multiple constraints approach was not able to determine if the soil has been losing or storing carbon. Nevertheless, the relaxed steady state assumption hardly introduced any additional uncertainty for the other parameter estimates.

Overall the results suggest that using $\Delta^{14}C$ data from more than one carbon pool or flux helps to better constrain SOC models.